Estimation of Adequate Maintenance Costs
of Bridge Maintenance

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ABSTRACT

In order to ensure rational budget management of road facilities and maintain road facilities efficiently, a nation has lead a process that can secure the best level of public using. This study embodies a model of function deterioration of asset management for placing the optimal asset value on bridges. For this embodiment, adequate management costs should be estimated through examining and analyzing maintenance costs caused by maintenance work for bridges. Additionally, it should be reflected in asset management system.
Therefore, in this study, it is examined patterns and relevance of maintenance items affected by condition transition of bridges and maintenance costs. Also the relationship between deterioration of bridges and investment for bridges are observed. We target PSC (Pre-stressed Concrete) Beam Bridge, which is the most widely used in domestic bridges, to monitor and analyze how much doing maintenance work and how having influence on the lifetime of a structure. By utilizing this model, we provide a standard that can be applied to an adequate estimation for future maintenance and management cost for bridges based on condition transition model, which is made of real history records of PSC beam bridges

1. THE BACKGROUND AND PURPOSE OF STUDY

Highways of Korea enhanced the quality and efficiency of life as a one-day life zone due to continuous construction and renovation for last decades.
In addition, the users' requirement for better service is increasing cost for maintenance and management for aged facilities is becoming a prominent issue. In other words, discussions about maintenance cost and quality for existing road facilities are enlivened. Therefore, the Ministry of Land, Transport and Maritime Affairs (MLTM) is developing the facility systems as a national asset management to searching for ways to enhance efficiency. For these reasons, this research aims to develop function deterioration model using transition probability of condition index about a bridge type of Pre-stressed Concrete Beam (PSC Beam), which is a representative type of several upper types of bridges.

To develop Transition probability of PSC Beam Bridge, it was studied about time block and probability of bridges. And, transition model of condition index for internal life extension upon analysis. Eventually, it aims to surmise the appropriate cost, period and volume based upon given models.

2. RESEARCH FOR BRIDGE MAINTENANCE AND MANAGEMENT OF DOMESTIC AND FOREIGN CASES

2.1 Domestic Bridge Maintenance Researches

The real bridge maintenance began in the middle of 1990's in reality, when we had a bridge collapse accident during service life. Since then, various bridge maintenance system, field activities and many research began to develop the method of maintenance. Korea Institute of Construction Technology was one of the developers and suggested the necessity of LCC considering to maintenance cost suggesting a study about improvement of previous Bridge Management System (BMS), and it was a beginning of thinking for model of deterioration before maintenance and effect and maintenance.

In other hand, economic design was enacted in Administrative Law for Construction Technology Chapter 39, verse 13. Korea Public Corporation of Construction Safety, Korea Expressway Corporation, Korea Water Resources Corporation, and Korea Railway Corporation was supposed to catch up the new law. However, before 1990's, the Government did not recognize the importance of data base establishment for maintenance cost during public life of facilities. And the management administers for each facility did not perceived that the structure management data records would decide tomorrow's budget and maintenance decision. In addition, they did not think about the relation between appropriate maintenance time and life of infra structure. In 2000, each management administers used facility management system, but its goal was to accumulate only data not for maintenance and reinforcing-related record data accumulation, but for safety procedures record , check and checking history.

Recently, Korea Expressway Corporation recognized the importance of knowledge about expressway bridge maintenance, so they are now reorganizing previous HBMS (Highway Bridge Management System). And Korea Institute of Construction Technology began a study for bridge management system as a property management, which is for bridge structure's deterioration, function and making cost strategy. The period for the research would be surmised as between 2009 and 2011.

2.2 Foreign Bridge Management Analysis

Many developed countries try to analyze life-cycle performance make optimum decision considering relation between management cost and function transition for effective property management. For example, Pontis system of USA is the most leading one, because it can calculate bridge life-cycle analysis for management cost management. In USA, cost-related records are accumulated precisely and organization for life cycle management system is one of the most purchasable items. Pontis is the universal system, and each state of USA are customizing and using it. Also, it is used for Strategy Decision for Bridge Maintenance and Management by Transition probability for Condition Index for each bridge, and the process is divided by element level, project level and network level. Next step is bridge maintenance optimistic decision considering life-cycle performance analysis, management cost and performance change: it is for long-term property management.

However, the pros and cons of strategy decision for bridge maintenance and management using by transition probability for condition index is not appeared and needed to more research. For the life cycle management of performance, firstly, it is needed to define what is service life span and the evaluation way of bridge function during service life should be developed. For now, many countries are developing, but it is not enough because of data and technical limit. Therefore this study is to develop condition transition model for appropriate maintenance and management by condition index and it is to surmise proper maintenance cost depend on time variation and condition transition.

3. CONDITION CHANGE MODEL COMPOSITION STUDY

3.1 Evaluation Of Bridge Condition State

This study investigates and analyzes condition index of bridges on public road and on expressways, because condition index is the only reason recording function and condition of domestic

roads and express ways. Condition index has five levels of A, B, C, D and E for condition, each element's importance and defects are reflected on the whole condition.
Bridge evaluation includes three options: stability (related with load-durability), usability (Tremble, Sinking) and durability (related with bridge life span). Unlike stability, usability and durability is not easily evaluated, so domestic and oversee researchers are trying to make objective standards. In addition, correct investigation for early time is important in bridge evaluation; in other words, after deterioration, the transition is accelerated. To prevent bridge deterioration, it is best to know deterioration type and process for each bridge type, especially about most common deteriorations. However, most of deterioration is not predicted, yet.

3.2 Condition State Of Deteriorated Bridge

The observation method of appearance is for checking bridge deterioration in many countries: USA, Japan, France and Canada Ontario. Bridge deterioration index are levelled and weighted by deterioration type, importance of elements and reason of deterioration.(Table 1)

Table 1 Relative evaluation index [5]

<table>
<tr><td>Evaluation Criteria</td><td>Condition</td><td>Evaluation Criteria</td><td>Condition</td></tr>
<tr><td>A</td><td>Trivial Deterioration
Investigation
Treatment if necessary</td><td>C</td><td>Not Serious Deterioration
Treatment if necessary as soon as possible</td></tr>
<tr><td>B</td><td>Not Serious Deterioration
Investigation
Treatment if necessary</td><td>D</td><td>Serious Deterioration
No Emergency Treatment
Treatment if necessary</td></tr>
<tr><td colspan="2">Evaluation Criteria</td><td colspan="2">Condition</td></tr>
<tr><td colspan="2">E</td><td colspan="2">Serious Deterioration/Prohibit Pedestrians
Emergency Treatment</td></tr>
</table>

3.3 Markovian Theory and Transition Probability

3.3.1 Markovian Process Model

Markovian process model is a useful method to research repetitive transition or progressive process for specific system. According to this model, a certain case or examination result is decided only by previous case or examination result, and it was developed by a Russian mathematician, A.A Markov(1856-1922). Markovian process analyzes probability of transition or progressive process for specific system using transition matrix which represents probability of system transition. Decision problem should be decided only by previous cases and the result should be one of dispersive probability variables. Markov chain model's original purpose was to predict probability of condition transition, and this research uses Markov chain model to predict condition transition for bridge maintenance and management according to transition probability between unit time blocks and to decide appropriate maintenance and management level. [2]
A stochastic process whose state at time t is *X(t), t>0* ,and whose history of states is given by *x(s)* for times *s< t* is a Markov process if

$$\Pr[X(t+h)=y \mid X(s)=x(s), \forall s \leq t] = \Pr[X(t+h)=y \mid X(t)=x(t), \forall h > 0 \qquad (1)$$

That is the probability of its having state *y* at time *t+h*, conditioned on having the particular state *x(t)* at time *t*, is equal to the conditional probability of its having that same state y but conditioned on its value for all previous times before *t*. This captures the idea that its future state is independent of its past states. Markov processes are typically termed homogeneous if

$$\Pr[X(t+h)=y \mid X(t)=x] = \Pr[X(h)=y \mid X(0)=x], \forall t, h > 0 \qquad (2)$$

and otherwise are termed inhomogeneous (or non-homogeneous). Homogeneous Markov processes,usually being simpler than inhomogeneous ones, from the most important class of Markov processes.
In some cases, apparently non-Markovian processes may still have Markovian representations, constructed by expanding the concept of the 'current' and 'future' states. For example,

let *X* be a non-Markovian process. Then define a process *Y*, such that each state of *Y* represents a time-interval of states of *X*, i.e mathematically,

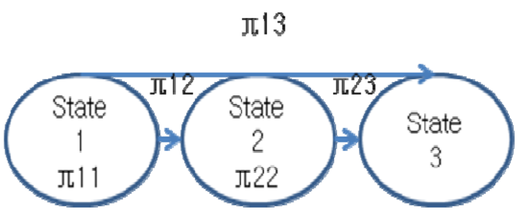
$$Y(t) = \{X(s) : s \in [a(t), b(t)]\} \tag{3}$$

If *Y* has the Markov property, then it is a Markovian representation of *X*. In this case, *X* is also called a second-older Markov process. Higher-order Markov processes are defined analogously.

3.3.2 Transition Probability Adaptation

Transition probability of Markovian process model means the probability of change from a specific condition to another condition in repetitive experiments. This research composed 5 year unit time blocks of highways and expressways to study bridges' transition probability for condition index. Specially, domestic bridge has records for condition index less than 15 years and previous data does not exist, Transition probability for condition index of public life span less than 20 years was established. This model based on real data would have a lot of difference from experimental model, but it is very important to show the bridges' extant reality of maintenance and management.

The Transition probability model adopted 3-state-Markov model: for now, there are level A,B and C, because bridges lower than level C should have a treatment and reinforcement to raise upper than level B. Therefore, the level D has no records and only surmised. Figure 1 shows 3-state-Markov model, and its condition space is Equation (4).



$$\pi = \begin{pmatrix} \pi 11 & \pi 12 & \pi 13 \\ 0 & \pi 22 & \pi 23 \\ 0 & 0 & 1 \end{pmatrix} \tag{4}$$

Figure 1 3-State-Markov model and condition space

$$P = \begin{pmatrix} p11 & p12 & p13 \cdots & p1k \\ 0 & p22 & p23 \cdots & p2n \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots\cdots & pkk \end{pmatrix} \tag{5}$$

4. CONDITION EVALUATION MODEL DEVELOPMENT OF PSC BEAM BRIDGES ON NATIONAL ROADS AND EXPRESS WAYS

4.1 Condition State of PSC Beam Bridge

In sum, 67 PSC Beam bridges on the Roads were investigated about main maintenance and treatment and recent condition index to build a condition evaluation transition Model. The investigated bridge was chosen randomly and the age of bridges, which are managed as a nationally important No.1 bridge, is between 5 and 31 years old. The location and volume for each bridge is various. The official life-span and its variety follow below. In 2008, 30% of PSC Beam bridges under government's management are less than 5 years old, and 65% of the bridges are less than 15 years old.(Table 2)(Figure 2)

Transitive history of transition index for each period is shown at the Table 4. Among bridges over 20 year's official life-span, some has no records their history, because Transition Index was recorded since Sung-soo bridge collapse in 1994. It is possible for the old bridge to have a management, but they do not have full records since construction. condition curve model for appropriate bridge management for every year of life-span was established to suggest management level of PSC Beam bridges on the Roads. Also, the curve model for most ideal management would be suggested.

The scope of maintenance and management budget according to each condition index transition would be suggested statistically to make a bridge maintenance and management strategy.

4.2 Estimation of the Transition Probability for Condition Index in PSC Beam Bridges

To estimate the transition probability for condition index in general and expressway bridges the transition probability model has been designed using Hidden Markov Method (HMM). The transition or generation probability should be acquired with observed data only. In other words, it comes down to the matter of how to induce the information on state transition using the output sequence only.[1]

Table 2 Condition range and ratio to service years

Service year	Rate	A	B	C
1-5Y	0.30	0.09	0.21	
6-10Y	0.19	0.06	0.13	
11-15Y	0.16		0.12	0.13
16-20Y	0.13		0.04	0.09
21-25Y	0.12		0.04	0.07
26Y-31Y	0.09		0.07	0.01
Total	1.00	0.15	0.63	0.31

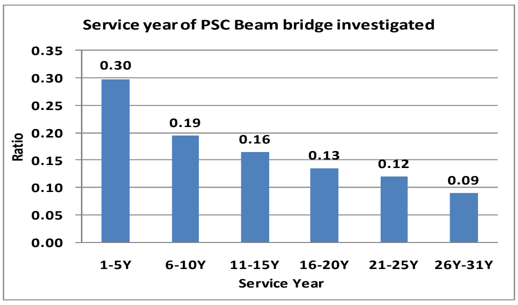


Figure. 2 Service year of PSC beam bridge investigated service years

Table.3 History on condition transition of highways and expressways on PSC beam bridges
(Left table :Highway transition history, Right table :Expressway transition history)

Bridge_Name	Completion	Service year	1-5Y	6-10Y	11-15Y	16-20Y	21-25Y	26-30Y	31-35Y
			Conditon level	Conditon level	Conditon level	Conditon level	Conditon level	Conditon level	Conditon level
1대성교	1987	21			0→C	C→C			
					C→C	C→C			
						C→B			
						B→B			
						B→B			
1입암교	1985	23			0	0→B	B→B		
					0	B→B	B→B		
						B→B			
가미교	1981	27				B	B→C	C→B	
						B→B	C→C		
각계교	1994	14		A	B→B				
				A→B	B→B				
각서3교(하)	1998	10	A	A→B					
			A→A	B→B					
				B→B					
갈천2교	1994	14		0	B→B				
				0→A	B→B				
				A→B					
감로2교(상행선)	2006	2	A						
			A→B						
감로2교(하행선)	2006	2	A						
			A→B						
감로 3교(상행선)	2006	2	A						
			A→B						
감로3교(하행선)	2006	2	A						
			A→B						
감천1교	1987	21			0	B→B	B→B		
					0	B→B			
					0→B	B→B			
감천2교	1987	21			0	C→C	C→B		
					0	C→C			
					0→C	-			

Bridge_Name	Completed	1-5Y			6-10Y			11-15Y		
		Inspcetion	Cost($)	Condition_Index	Inspcetion	Cost($)	Condition_Index	Inspcetion	Cost($)	Condition_Index
88 낙동강교 (고서)	84.08.15									
갈산천교 (목포)	01.11.20	정밀점검 02.04.01	0	A등급	정밀점검 08.03.01	0	A→A			
		정밀점검 04.04.01	50	A→A						
		정밀점검 06.10.30	0	A→A						
갈산천교 (서울)	01.11.20	정밀점검 02.04.01	0	A등급	정밀점검 08.03.01	0	A→A			
		정밀점검 04.04.01	50	A→A						
		정밀점검 06.10.30	0	A→A						
강동1교 (상행)	04.12.21	정밀점검 06.09.12	0	A등급						
		정밀점검 08.03.04	0	A→A						
강동1교 (하행)	04.12.21	정밀점검 06.09.12	0	A등급						
		정밀점검 08.03.04	0	A→A						
강동2교 (상행)	04.12.21	정밀점검 06.09.12	0	A등급						
		정밀점검 08.03.04	0	A→A						
강동2교 (하행)	04.12.21	정밀점검 06.09.12	0	A등급						
		정밀점검 08.03.04	0	A→A						
강동대교 (판교)	02.12.20	정밀점검 03.05.12	0	A등급	정밀점검 08.09.01	0	A→A			
		정밀점검 04.10.10	0	A→A						
		정밀점검 06.06.29	0	A→A						
고가교(퇴계	91.12.07	정밀점검 96.07.04	148,476	B등급				정밀점검 02.09.09	0	B→A
								정밀점검 04.10.04	0	A→B
검암천교 (목포)	01.11.20	정밀점검 02.04.01	0	A등급	정밀점검 06.10.30	0	A→A			
		정밀점검 04.04.05	30	A→A	정밀점검 08.03.10	0	A→A			
경호감2교 (통영)	98.12.11	정밀점검 02.06.26	0	A등급	정밀점검 04.10.15	0	A→A			
		정밀점검 02.08.30	0	A→A	정밀점검 06.05.31	0	A→A			
					정밀점검 08.05.28	249,752	A→B			
경호감2교 (하남)	98.12.11	정밀점검 01.10.18	0	A등급	정밀점검 04.10.15	0	A→A			
		정밀점검 02.08.26	0	A→A	정밀점검 06.05.31	0	A→A			
		정밀점검 02.08.30	0	A→A	정밀점검 08.05.28	249,752	A→B			

The condition curve from the transition probability model in the PSC beam bridges is analyzed as follows: In case of P (transition probability), it was hard to find formula that provides consistent value. Therefore, the transition probability model was created in two stages; P00 and P11.The P00 stage

was designed based on the transition probability model primarily using 15-year-long, official life-cycle data. Here, considerably approximate value is provided. On the contrary, P11 is a transition probability model which is based on targeting appropriate maintenance and management to extend official life cycle. The transition matrix P11 is for the service life of 60 years. To compare the costs necessary for the maintenance and management, the following models have been proposed.

$$P00 = \begin{pmatrix} 0.3 & 0.7 & 0 \\ 0 & 0.85 & 0.15 \\ 0 & 0 & 1 \end{pmatrix} \quad (6) \qquad P11 = \begin{pmatrix} 0.89 & 0.11 & 0 \\ 0 & 0.80 & 0.20 \\ 0 & 0 & 1 \end{pmatrix} \quad (7)$$

The follow matrix is transition matrix based on from time block t=5 to time block t=20 year, which is translated by P00.

$$P^{(0)}(t=5) = \begin{pmatrix} 0.3 & 0.7 & 0 \\ 0 & 0.85 & 0.15 \\ 0 & 0 & 1 \end{pmatrix} \qquad P^{(1)}(t=10) = \begin{pmatrix} 0.09 & 0.81 & 0 \\ 0 & 0.72 & 0.28 \\ 0 & 0 & 1 \end{pmatrix}$$

$$P^{(2)}(t=15) = \begin{pmatrix} 0.03 & 0.75 & 0.23 \\ 0 & 0.61 & 0.39 \\ 0 & 0 & 1 \end{pmatrix} \qquad P^{(3)}(t=20) = \begin{pmatrix} 0.01 & 0.65 & 0.34 \\ 0 & 0.52 & 0.48 \\ 0 & 0 & 1 \end{pmatrix} \quad (8)$$

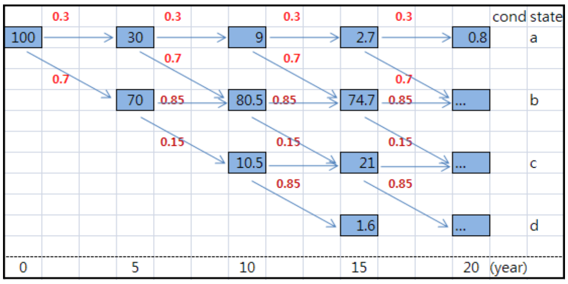


Figure 3 Transition probability base on Real Data

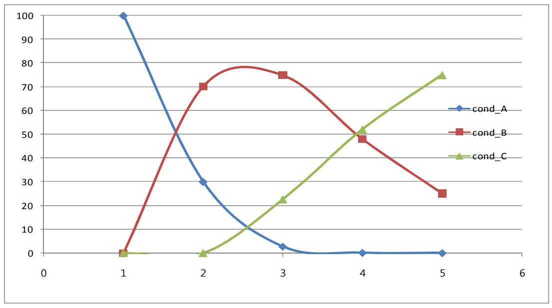


Figure 4 P00-based transition probability Model

Figure 4 show P00-based transition probability model and figure 5 describes the time consumed for transition from the condition state 'A' based on the transition probability as shown in highways of Figure 4.

The graphs illustrated in this paper can be explained in two types: One is the graph based on transition probability while the other provides transition curve graphs by service year by multiplying the weighted condition indexes by the transition probability of condition index. In Figure 5 where the latter is shown, the fluctuation in condition index and the slope of transition curve can be compared by service year.

In case of the bridges with 27.5 years of average service life, for example, there exists no record on the change in condition index for the past 15 years. In this paper, the condition index during this unknown period has been assumed as 'A'. This paper has established Markov Transition Model in consideration of the transition probability model of the bridges with 15 or less years of average service life.

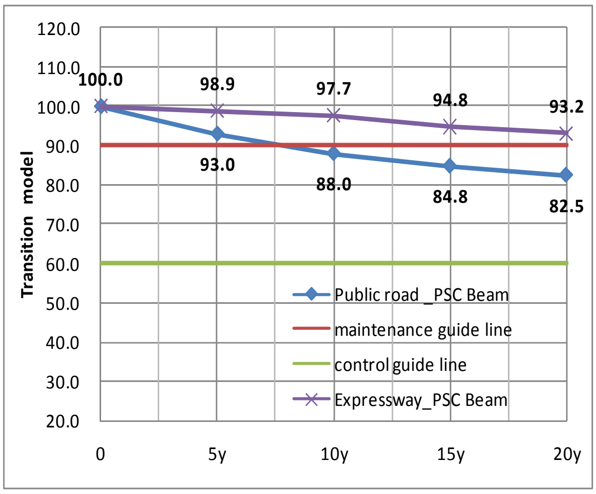


Figure 5 Transition model curve based on the transition probability P00 and P11 curve

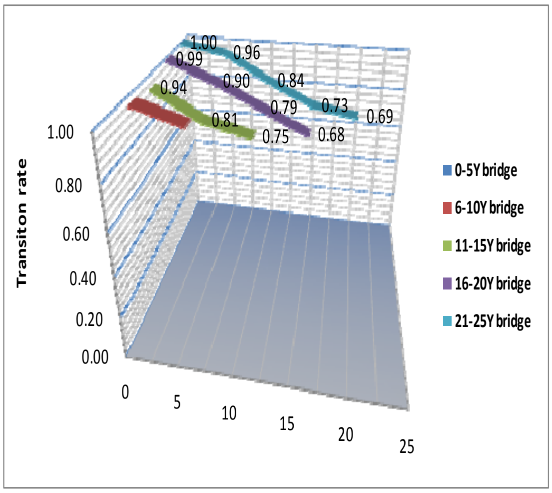


Figure 6 Weighted value-based transition model

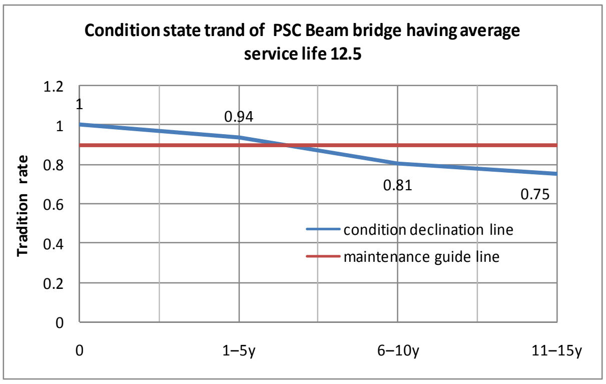


Figure 7 The condition transition curve of the bridges with 12.5 years of average service life

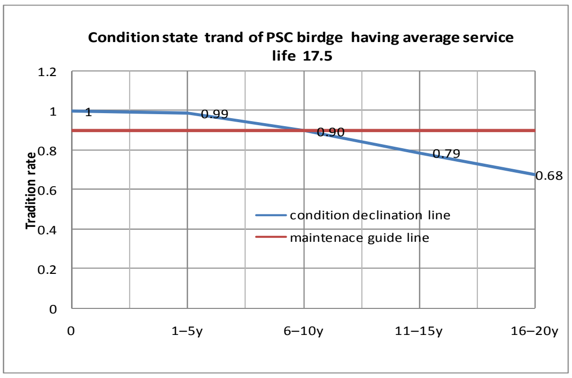


Figure 8 The condition transition curve of the bridges with 17.5 years of average service life

Even though it is very difficult to consistantly apply service life to all bridges, the Markov Transition Model used in this paper is very significant because it has been designated based on actual data. The additionally proposed transition proabability model P11 is a somewhat idealized model which has been established based on the early transition probability of condition index by service life.

4.3 Estimation of the Transition Probability of Condition Index in Expressway PSC Beam Bridges

This paper has also analyzed expressway PSC beam bridges under the same analytical conditions. In expressway, condition index was analyzed agaisnt 60 PSC beam bridges. In addition, the management and maintenance cost by bridge condition has been investigated as well. The 60 bridges were classified by condition state (‘A,’ ‘B,’ ‘C,’ etc.) and shown in the table below.(Table 4)

In the bridges with 5 or less years of average service life, all of them (100%) maintained the condition state ‘A.’ In the bridges with 12.5 years and 17.5 years of average service life, the ratio of transition from ‘A’ to ‘B’ was 33% and 37.5% respectively.

The transition probability in the expressway bridges has also been developed in two types just like the transition probability in the bridges on the general roads. In other words, the transition probabilty model and the transition curve model by service life in consideration of weighted condition indexes were proposed.

Table 4 Condition index rate per service life

Service year	Bridge_No	Rate	A	B	C
1-5Y	21	0.32	0.32		
6-10Y	18	0.28	0.18	0.09	
11-15Y	8	0.12	0.02	0.11	
16-20Y	13	0.20	0.06	0.08	0.06
21-25Y	5	0.38	0.00	0.03	0.05
Total	65	1.00	0.63	0.30	0.07

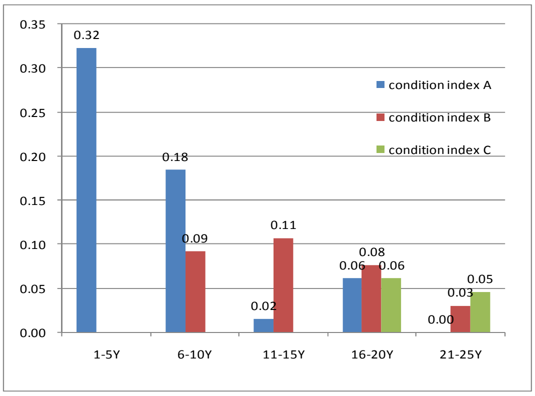


Figure 9 Condition state per service Life

Table 4 and figure 9 explain condition state index ratio following time variation. Service year 1-5 year group ,6-10 year group, and 16-20 year group are aduquate data sets ,but other groups have few data group and provide to difficult to analysis of transition matrix.

Figure 10 shows the state decline model by service life in the expressway PSC beam bridges. In general, many people believe that expressway bridges have a longer design life and safer design than the bridges on the general roads. Therefore, it has been estimated that there would be a difference in the condition index decline rate.

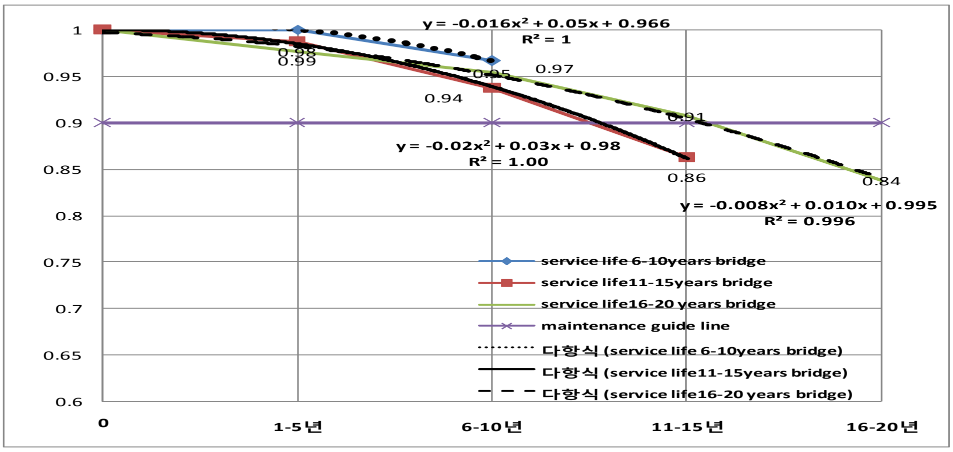


Figure 10 State decline curve by service life in the expressway PSC beam bridges

From figure 10, remaining life time in case of no repair and no-maintenance is about 33 years. It's life is based on 16-20 years group and if you calculate their remaining life time in the basis of 11-15 service life group, the life is about 27 years shorter than that of other group. Herein remaining life time means that drop to condition state index 'C' is the last deadline to perform the repair.

In addition, since most expressway PSC beam bridges are 20 or less years old, it is assumed that the condition evaluation-related data are well stored. The transition probability graphs based on the transition probability model are as follows:

$$P00' = \begin{pmatrix} 0.74 & 0.26 & 0 \\ 0 & 0.89 & 0.11 \\ 0 & 0 & 1 \end{pmatrix} \quad (9) \qquad P11' = \begin{pmatrix} 0.88 & 0.12 & 0 \\ 0 & 0.85 & 0.15 \\ 0 & 0 & 1 \end{pmatrix} \quad (10)$$

.

Where, $P'^{(N)}$ (N=0,1 ,2) is a transition matrix based on P00' and transition ratio due to time is as follow

$$P'^{(0)}(t=5) = \begin{pmatrix} 0.74 & 0.26 & 0 \\ 0 & 0.89 & 0.11 \\ 0 & 0 & 1 \end{pmatrix} \; P'^{(1)}(t=10) = \begin{pmatrix} 0.55 & 0.45 & 0 \\ 0 & 0.42 & 0.58 \\ 0 & 0 & 1 \end{pmatrix} \; P'^{(2)}(t=15) = \begin{pmatrix} 0.41 & 0.52 & 0.07 \\ 0 & 0.37 & 0.63 \\ 0 & 0 & 1 \end{pmatrix} \quad (11)$$

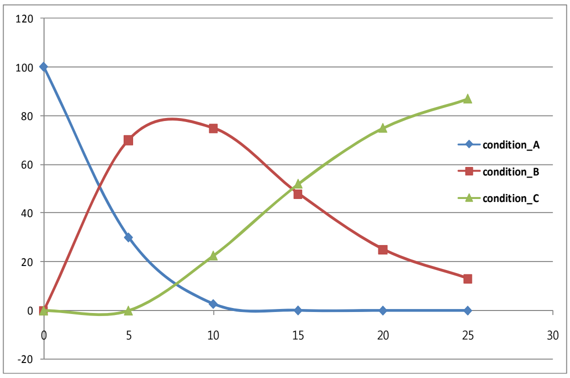


Figure 11 Transition probability model of PSC beam expressway bridge

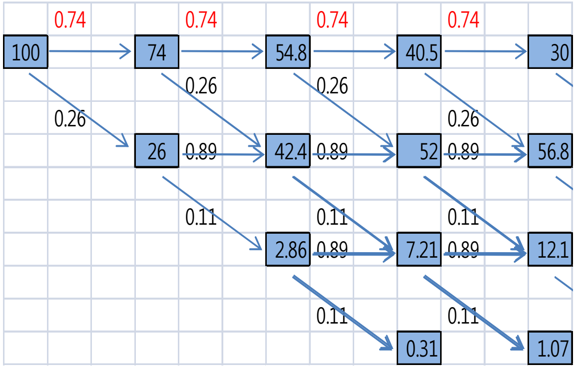


Figure 12 Transition model based on the transition probability P00'

Unlike the bridges on the general nation roads, the expressway bridges show stable value in terms of transition probability. In addition, this paper has conducted an analysis based on the input data on the conventional maintenance and management cost in order to suggest the optimum management and maintenance investment cost depending on the change in condition index through this model. Furthermore, the average input cost related to service life and condition transition has been analyzed. Then, the cost ratio has been suggested for improvement of condition index.

4.4 Estimation of Maintenance Cost Based On The Transition Model of Condition Index

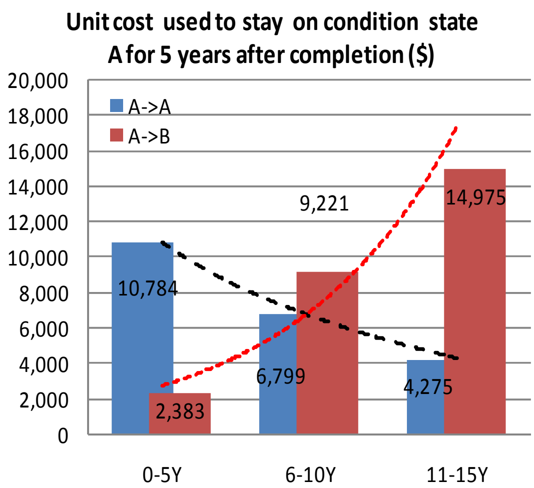
Since the 67 PSC beam bridges used in this paper have the data on input cost related with the change in condition index, the current status of overall cost input could be analyzed. Based on the total cost used to maintain the condition state 'A' and 'B,' unit cost has been calculated, which is also useful in preparing a future maintenance and management plan as well as in figuring out the size of actual input cost. In other words, this paper tried to show that 1) the analysis on the weakness by the type of bridge and the optimum period for maintenance and management would help to extend bridges' life span from a long-term perspective, and 2) the current maintenance and management-related data would play an important role in establishing a future maintenance and management strategy. The ratios acquired in this analysis will be applied to the cost for condition index management that meets target management criteria in combination with the real transition probability of condition index. Even though this cost analysis is based on reliable data and grounds, it would not be fully satisfying. However, it has no problem in analyzing the overall trends. Then, the transition probability model and cost input in the PSC beam bridges on the general roads can be stated as follows: In the beginning, a lot of money was used to maintain the condition state 'A.' As time went by, however, money was used to prevent further degradation after the condition state was degraded from 'A' to 'B.' In other words, the cost used to maintain each condition index by service life can be checked. In case of the bridges with 5 or less years of average service life, cost is mostly used to maintain the condition state 'A.' In the bridges with 11-15 years of average service life, on the contrary, more money (nearly 6.2 times) is used to prevent them from falling into the condition state 'B' for early five (5) years. This shows that the ratio of being degraded into the 'B' level has decreased because of a great advance in architectural and construction technology.

Table 5 Condition index transition ratio and unit cost relation per service year

Condition	Service year (0-5)		Service year (6-10)			Service year (11-15)			
	A->A	A->B	A->A	A->B	B->B	A->A	A->B	B->B	B->C
Unit Cost	10,784	2,383	6,799	9,221	11,026	4,275	14,975	2,727	5,679
ratio	0.16	0.04	0.10	0.14	0.16	0.06	0.22	0.04	0.08

The figure above(Figure 13,14) shows the unit cost used to stay on original state for 6-10 years after completion. Even though the number of bridges that stay on condition state 'A' has greatly decreased compared to the figure during the early five years, a greater amount of money has been spent to stay on condition state 'A' for 6-10 years after completion. Specifically, a total of 5600$ was

spent for the bridges with 6-10 years of average service life while a greater amount of money was spent for the bridges with 11-15 years of average service life for the past 10 or less years.



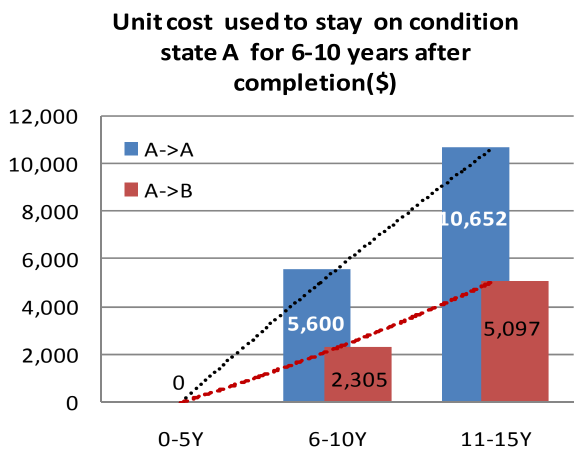
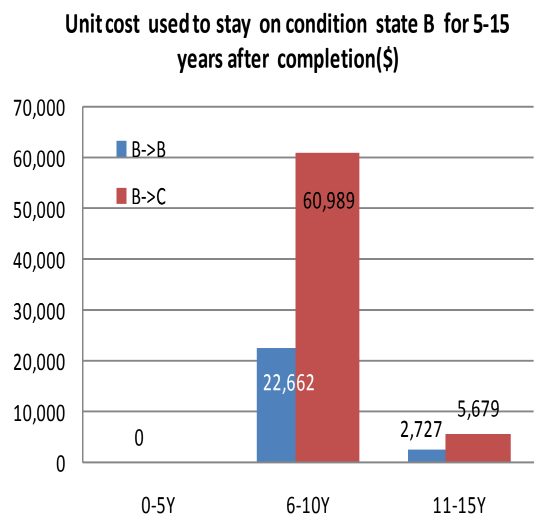


Figure 13 Unit cost to condition 'A' for 5 years after completion

Figure 14 Unit cost to condition 'A' for 6-10 years after completion

Meanwhile, even through bridges are the same in terms of structural patterns, the maintenance cost has changed over time due to an advance in engineering and construction technology. According to the analysis on maintenance cost of the bridges in condition state 'B,' the unit cost used to stay on condition state 'B' for 10 or less years after completion turned out very high.

When compared to the bridges with less than 15 years of average service life, the unit cost was nearly 11.6 times higher. It appears that the maintenance has been active to stay on current state.The figure(Figure 16) illustrates the relationship between the cost used to stay on current condition state and changes in condition index. At present, Korean law requires that bridges should stay on condition state 'B.' This level must have preserved in and around 90 points and reinforced the bridge in the minimum level of 60 points.(Figure 16) The red line stands for the transition curve of condition index by service life, which has been obtained through the transition probability model. In general, the condition state starts to change in 7-8 years after completion in case of PSC bridges on the general roads Even though this cost has been induced from the relationship with the previous input cost, a further study needs to be conducted on the size of and right time for optimal cost.



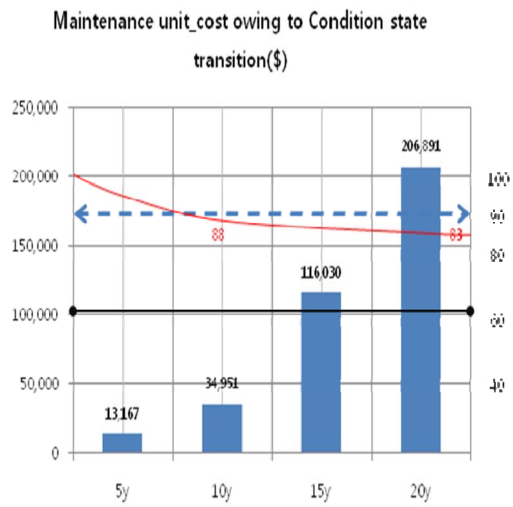


Figure 15 Unit cost to condition 'B' for 5-15 years after completion

Figure 16 Maintenance unit cost owing to condition state transition according to time

Table 6 Condition index transition ratio and unit cost relation per service year($)

Service Year	SERVICE LIFE 5		SERVICE LIFE 10			SERVICE LIFE 15			SERVICE LIFE 20		SERVICE LIFE 25			SERVICE LIFE 40
	A->A	A->B	A->A	A->B	A->C	A->A	A->B	B->B	A->B	B->B	B->B	B->C	C->C	C->C
1-5Y	1,000	0	130	14,300	49,500					148,476				
6-10Y			63,800	749,256		13,000			121,834					
11-15Y							1,077,491	126,090						
16-20Y										381,662		56,087	101,517	
21-25Y												144,185	151,625	
26-30Y														
31-35Y														112,622
36-40Y														80,000

This table(Table 6) is a cost data used to repair and reinforcement of expressway PSC beam bridges. A similar to highway roads, it is compared to transition provability of condition state index and investment cost to protecting present condition. Especially cost data is not perfect and many cost data related to maintenance have been left off, but this data is provided from Accurate Safety Examine result Report.

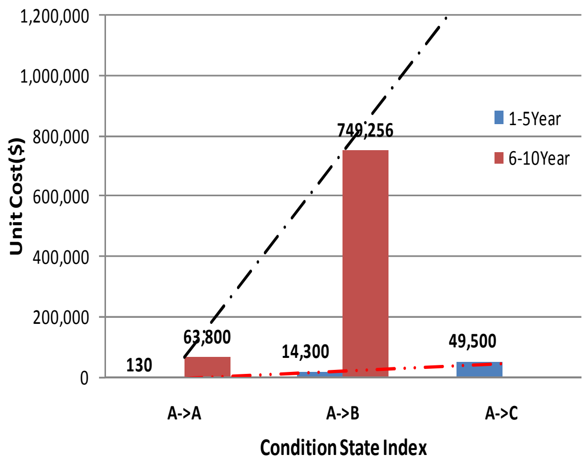


Figure 17 Unit cost to condition 'A' for 10 years after completion

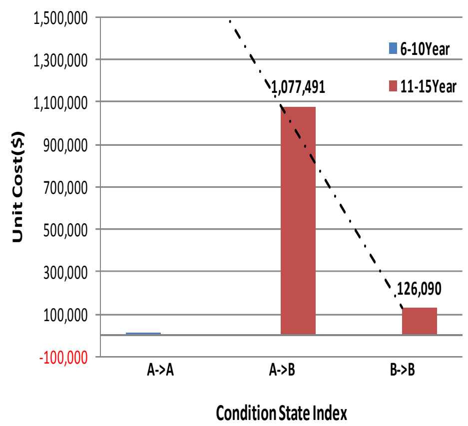


Figure 18 Unit cost to condition 'A'and 'B' for 6-15years after completion

These figures(Figure 17 and 18) show the maintenance cost of PSC beam bridge on expressway ,which is expended to protecting the present condition state. By comparision with maintenance cost of highway and expressway of PSC beam bridge, there is difference of about 20 times. This numerical value is very important because expressway have aim to maintenance providing high quality service for public users. It is difference of two operation government.

5. CONCLUSION

This paper has investigated the transition probability of condition index on the PSC beam bridges on expressway and national road, and developed the transition probability model based on the investigation. In addition, the cost used to stay on current condition state has been analyzed in relation with change in condition state. It is proved that the transition probability of PSC Beam bridges of public national roads is faster than that of same bridge in expressways. Based on this analysis, this paper has investigated the optimal unit cost used to stay on condition state per time block on the expressway and general roads, and tried to search for the cost-put-in-period and reasonable cost to lead the management and maintenance up to the network level. The Unit cost used to maintain condition 'A' is 2 times less than to maintain condition 'B'. Data management and continuous concern for infra structure maintenance are needed absolutely to saving the national budget.

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